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(12) UK Patent Application (19) GB (11) 2 119 358 A

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- (21) Application No 8310439  
(22) Date of filing 18 Apr 1983  
(30) Priority data  
(31) 373472  
(32) 30 Apr 1982  
(33) United States of America (US)  
(43) Application published 16 Nov 1983  
(51) INT CL<sup>3</sup>  
C04B 21/00  
(52) Domestic classification  
C1H 120 620 690 711 727  
742 756 757 813  
E1F PC  
(56) Documents cited  
US 3931096  
US 3943996  
(58) Field of search  
C1H  
E1F  
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(54) Lightweight cement slurry

(57) A foamed, cement slurry comprises an aqueous hydraulic cement slurry containing gas as discrete entrained bubbles and a specific quaternary ammonium compound as a foaming agent which has the formula  $R R_3 N^+ X^-$  where  $X = Cl, Br, I$  or  $OH$ ,  $R = C_{8-16}$  aliphatic hydrocarbyl, and  $R'$  (independently each occurrence) =  $C_{1-3}$  alkyl or hydroxyethyl and the sum of C atoms in  $(R+3R')$  is not greater than 20;

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## SPECIFICATION

## Lightweight cement slurry and method of use

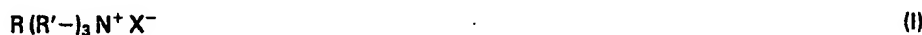
5 The invention is a lightweight aqueous foamed cement slurry and a method of using same to fill a subterranean void. The slurry is particularly useful in the art of oil and gas well cementing. 5

Cement slurries have been foamed as a method of lightening such slurries for use in oil and gas wells or for subterranean grouting; U.K. Patent 819,229; ASME Paper No. 75 PET-10 (1975). U.S. Patent 3,926,257 suggests adding a foaming agent to a cement slurry which foaming agent later collaborates with gas 10 escaping from a gas-containing formation to form a foam barrier to prevent subsequent migration of gas during the setting of the cement. It is stated that the foaming agent may be a nonionic, anionic, or cationic. The cationic surfactant is broadly stated to be "a quaternary ammonium salt". The only embodiment specifically mentioned is a mixture of an oxyethylene aliphatic compound and at least one sulfate of a polyethoxy fatty alcohol. In U.S. Patent 4,300,633 it is stated that the foaming agents to be used must be 15 active in a highly alkaline environment and show resistance to multivalent organic cations if sea water is used. Anionic surfactants, specifically organic alkali metal sulfates or sulfonates are said to be particularly suitable for this purpose. 15

The present invention basically resides in a foamed hydraulic cement slurry comprising an aqueous slurry of hydraulic cement, entrained gas bubbles and a foaming agent selected from certain specific quaternary ammonium compounds. The cement slurry is superior to foamed cement slurries prepared from other 20 quaternary ammonium compounds and from other nonionic and anionic surfactants. When prepared with the specified foaming agents, a stable, uniform foam of relatively small bubble size is rapidly formed in which there is relatively little segregation of the liquid, solid and gaseous components. Hardened cement prepared from such slurries in many cases exhibits superior strength and low permeability when compared 25 with hardened foamed cements prepared utilizing other foaming agents. The invention further comprises a process of cementing subterranean voids by emplacement of this slurry to give a strong, impermeable seal in applications such as the grouting of underground bore holes and plugging the voids created or encountered during the drilling of oil, gas or geothermal wells. Because of the light weight of the slurry, the breakdown of weak formations during cementing of such subterranean voids is avoided. 25

30 Foamed slurries of the invention exhibit an additional advantage of maintaining their foamed nature at temperatures in excess of about 65.6°C (150°F), and even in excess of about 93.3°C (200°F). At such temperatures, foamed cement slurries prepared with other than the foaming agent of this invention may begin to collapse before the slurry has hardened. 30

The foaming agent utilized in the instant invention which permits attainment of these desirable benefits is 35 a composition represented by the formula 35



wherein X is chloride, bromide, iodide or hydroxyl, R is a aliphatic hydrocarbyl radical comprising from 8 to 16 carbon atoms and R' is, independently each occurrence, an alkyl radical of one to three carbon atoms, or 40 hydroxyethyl, and the sum of the carbon atoms in R and all R' is not greater than about 20. 40

More particularly, the invention resides in a foamed hydraulic cement slurry comprising a gas-containing aqueous slurry hydraulic cement and a foaming agent represented by Formula I. The invention further resides in a method of plugging a subterranean void by emplacing the foamed cement slurry in the 45 subterranean void and allowing the slurry to harden. The foamed slurry is preferably emplaced in a borehole drilled for an oil or gas well or in the annulus created between the borehole and the casing of such a well. Except for the equipment adapted for the generation of the foam, as described more fully hereafter, standard oilfield equipment and emplacement methods may be utilized to carry out the process of the invention. 45

The necessary elements of the foamed cement slurry of the invention are an aqueous slurry of hydraulic 50 cement, prepared by adding water to a hydraulic cement component, which preferably comprises Portland cement, a gas which is entrained as discrete bubbles in said aqueous cement slurry and a foaming agent represented by Formula I. The aqueous cement slurry, as described more fully below is commonly mixed in the usual fashion and thereafter the foaming agent and gas are added to the slurry in an enclosed conduit. 50

The most important element of the foamed slurry of the invention is the foaming agent which is a 55 quaternary ammonium compound represented by Formula I, above. In Formula I, R represents a hydrocarbyl group having from 8 to 16 carbon atoms and preferably from 10 to 14 carbon atoms. R may be saturated or unsaturated and is suitably selected from fatty alkyl groups having from 8 to 16 carbon atoms. Preferably, R is a straight chain hydrocarbyl radical. More preferably, R represents a mixture of hydrocarbyl radicals derived from a vegetable oil such as cocoa oil. In the so called "coco" alkyl groups, the carbon chain length 60 may range from 8 to 16 carbon atoms with chains of 10, 12 and 14 carbon atoms predominating. 60 Accordingly, R may represent a mixture of such hydrocarbyl groups ranging from 8 to 16 carbon atoms or may be selected strictly from hydrocarbyl groups of one uniform chain length, i.e. the dodecyl group.

R' represents the other three hydrocarbyl radicals associated with the quaternary nitrogen atom. Suitably, R' is a one to three carbon alkyl radical or a hydroxyethyl radical, independently in each occurrence. 65 Preferably, it is an ethyl or methyl group, or is a hydroxyethyl group in up to two occurrences. More 65

preferably, R' is hydroxyethyl in up two occurrences or is methyl. The sum of all the carbon atoms in the R and R' groups associated with one quaternary nitrogen atom is suitably at least 12, preferably at least 13, and more preferably at least 14 carbon atoms and the sum is 20 or less, preferably 19 or less and more preferably 18 or less total carbon atoms.

- 5 In Formula I, X represents a chloride, bromide, iodide or hydroxyl radical; preferably it represents a chloride or hydroxyl radical and more preferably a chloride radical. Quaternary ammonium compounds of Formula I are widely known or may readily be prepared by known methods, for example by the reaction of an alkyl halide of the Formula RX with a tertiary amine of the formula  $(R' - )_3 N$  under known conditions. In some instances, where the foaming agent of Formula I exhibits limited solubility in water, a cosolvent such as iso-propanol may be added to I to permit full solubilization in the aqueous portion of the hydraulic cement slurry. The addition of other nonionic surfactants in conjunction with the foaming agent of Formula I may serve to enhance the stability of the foam in the aqueous cement slurry. Materials which are known foam stabilizers, such as low molecular weight polypropylene glycols of from 200 to 600 molecular weight, may suitably be used in addition to the agent of Formula I. Certain fatty amine oxides also serve in this fashion. 15 For example, bis(2-hydroxyethyl) cocoamine oxide combined with the foaming agent of I serves to form a uniform, stable foam in the aqueous hydraulic cement slurry. Likewise, ethoxylated derivatives of the quaternary compound of Formula I formed by the addition of several moles of ethylene oxide to a compound of Formula I where R' is hydroxyethyl in one or two occurrences, is a suitable adjunct to be used in combination with the compound of Formula I. For example, a compound prepared by the addition of about 20 15 moles of ethylene oxide to cocoamine and subsequent reaction with methyl chloride serves to enhance the foam stability of aqueous cement slurries containing the foaming agent of Formula I.

- The quantity of the foaming agent I to be added to the aqueous hydraulic cement is sufficient to permit the major portion of the gas to remain entrained as discrete bubbles in the slurry until the slurry has hardened sufficiently so that coalescence or migration of bubbles is no longer possible. This quantity will vary according to the other components and properties of this slurry and may be determined for a slurry by first measuring the API Standard RP10B "thickening time" of the slurry and then empirically determining the quantity of foaming agent needed to maintain the desired stable foamed slurry for that time under the conditions of temperature and pressure which will be encountered by the cement slurry after it is emplaced. To be certain that the stability of the foamed slurry is maintained, it is preferable to add excess foaming agent rather than too little. Commonly, by volume, at least about 0.1 part foaming agent per 100 parts of water, preferably at least about 0.3 part and more preferably at least about 0.5 part foaming agent will be adequate. Normally, about 3 parts, more preferably no more than about 2 parts and more preferably no more than about 1.5 part foaming agent per 100 parts water will be adequate to serve the intended purpose. However, as noted above, excess may be added without adversely affecting the resulting foamed slurry. 35 As is readily apparent, the foamed cement slurry will comprise solids, liquids (primarily water), and the entrained gas. The solid components of the cement slurry will primarily comprise the hydraulic cement component. Preferably this comprises a Portland cement and more preferably is selected from the categories of cements of Class A, C or G, set forth in Standards of the American Petroleum Institute (API) for use in oil and gas well cementing. In addition to Portland cements, cements known as high alumina cements are also useful for this purpose. 40

- Powdered anhydrous sodium silicate is another solid component which may be added to the aqueous cement slurry preferably in an amount of from 0.5 to 3 parts, by weight, per 100 parts of the hydraulic cement component. Other solid additives commonly incorporated in oil well cement slurries may likewise be added so long as they do not adversely affect the quality and stability of the foam. Such additives include fluid loss control agents, retarders, accelerators, extenders or fillers such as fly ash or pozzolans, finely divided silica as silica flour, sodium chloride, calcium chloride or sulfate, and the like. Thickeners such as bentonite and attapulgite, HEC, and the like are generally not employed in the invention slurries. Similarly, since a lightweight slurry is desired, hematite, barite or other such weighting agents are generally not added. Also, dispersing agents generally tend to degrade or destabilize the foam or cause separation of the liquid in solid phases, and for this reason will ordinarily not be employed. 50

Overall, the solids included in the foamed hydraulic cement slurry comprise, by volume, typically about 10 preferably at least about 15 up to about 35, preferably up to about 30 percent of the total foamed slurry.

- The second major portion of the foamed cement slurry is the portion made up of liquid components. Naturally, the major portion of such liquids is water but may further comprise liquid versions of the additives previously mentioned above such as fluid loss control agents, retarders, accelerators and sodium silicate solutions. The water may be relatively fresh water or may be an aqueous brine containing calcium chloride or sodium chloride, commonly produced from underground formation in oil and gas production of seawater. Preferably, the water to be employed is relatively fresh and lacking in dissolved mineral components. Typically, the liquid components will make up about 25, preferably at least about 30 percent up to about 60, preferably up to about 55 percent of the total volume of the foamed slurry. 60

- The gaseous portion of the foamed cement slurry is preferably added as a gas or mixture of gases to the preformed aqueous hydraulic cement slurry which already contains the foaming agent. Alternatively, the gas may be generated *in situ* by the chemical reaction of an active metal such as aluminum or magnesium with the strongly basic cement slurry to generate hydrogen gas. However, because of the explosive nature of hydrogen, such agents are more suitably replaced by synthetic gas blowing agents such as are employed in 65

the plastic foam generating arts. Suitably, organic nitrogen containing compounds which generate gaseous nitrogen when decomposed are preferred as *in situ* gas-generating agents. However, because of the general availability of compressed air, nitrogen and carbon dioxide in the oilfield, the addition of one or more of these gases to an aqueous hydraulic slurry containing the foaming agent is the method of choice in generating the foamed cement slurry of the invention. More preferably, nitrogen and/or air are so employed because of their lower solubility in aqueous solutions than carbon dioxide.

Gas suitably comprises, by volume, about 20 percent, preferably at least about 25 percent up to about 55 percent, preferably up to about 50 percent of the foamed slurry. When referred to herein, the volume of gas or of foamed slurry means that volume of gas or foam under the conditions at which the slurry will be used, e.g. pressure and temperature encountered in a subterranean void at which the foamed slurry is emplaced. This generally can be determined with sufficient accuracy from the ideal gas equation, i.e.

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

It is commonly available from tables used by those who pump nitrogen or carbon dioxide in oil and gasfield operations.  $V_2$  represents the volume of the gas under downhole temperature and pressure conditions,  $T_2$  and  $P_2$ , and  $P_1 V_1 T_1$  represent the pressure, volume and temperature of the gas in the foamed slurry upon preparation at the surface.

An "average diameter" of bubbles entrained in the hardened foamed slurry may be roughly approximated by cutting a statistically significant number of vertical cross-sections through the hardened slurry, measuring the visible bubbles' diameters, averaging the sum of these measured diameters and then doubling that number. A more accurate calculation of the average diameter may be obtained by multiplying the average of the measured diameters by  $4/3$ ; i.e., by 1.27. The average diameter of the major portion of the entrained gas bubbles is preferably less than about 1.0 mm, more preferably less than about 0.5 mm and most preferably less than about 0.3 mm. When employing the preferred foaming agents of the invention, the foam produced by strongly shearing the gas-containing hydraulic cement slurry will be a highly uniform foam with bubbles of a described average diameter and with only small amounts of bubbles having a diameter greater than 1 mm.

The foamed slurries of the invention are suitably prepared by first mixing the base aqueous hydraulic cement slurry with any standard cement blending equipment, such as a paddle mixing tank or a venturi-type cement slurry mixer. The means for preparing the slurry is not a critical element of the instant invention.

Once the slurry is prepared, it is suitably moved by a transfer means into an enclosed conduit suitable for transporting fluids. Oilfield treating pipe can easily serve as such a conduit. The slurry transfer means can be a common hydraulic pump such as a triple cylinder positive displacement pump commonly known as a "triplex" pump. This pump is widely used in the oilfield. The transfer means is not critical as long as it has the ability to transport a liquid/solid slurry with suitable velocity and a centrifugal pump may likewise be employed for this purpose. To the slurry in the conduit is added the foaming agent which may be injected into the slurry-carrying conduit by means of a small liquid blending pump connected to the conduit by a "tee" connection or a "Y-bend" connection in a suitable fashion. It is not advisable to add the foaming agent to the slurry upstream from the slurry transfer means, e.g. in the mixing apparatus, since addition at that point may cause air to be entrained in the slurry making it difficult to accurately measure the amount of gas entrained and difficult for all but especially designed pumps to handle such a foamed mixture. Such problems in handling may be avoided by adding the foaming agent directly at the suction of a pump utilized as a transfer means or immediately downstream from the transfer means to the conduit containing the aqueous slurry and foaming agent. The gas is then suitably added at a given rate to obtain the desired gas:liquid:solids proportions for the intended application. Ordinarily, for oilfield applications, sufficient gas is added to obtain a resulting foamed slurry of the density of from 600 to 1560 kg/m<sup>3</sup> (5 to 13 pounds per gallon). Pumping rates of either the slurry or of the gas may be adjusted so that the desired ratio is obtained.

The foamed slurry will be generated at the point of injection of the gas and injection may be accomplished by a "tee" connection to generate suitable turbulence at the point of mixing of the gas and the aqueous slurry. However, it is preferable to further shear the gas-containing slurry to obtain a smooth, uniform, small bubble size foam by dividing the conduit into two separate streams and then rejoining the thus divided streams in a mixing chamber by impacting the streams against one another at a common in-line focal point. This may be accomplished by forcing the two streams through orifices in a generally opposed fashion. Such a dividing of the slurry stream may be accomplished by a tee in the conduit, piping from the tee through two separate conduits which are then reconnected at another tee to cause the two opposing streams to mix at the junction of the tee. The resulting foamed slurry is then taken off as a single combined stream again. This combined stream then is conducted through the well bore tubing or the annulus into the subterranean void in the fashion well known in the oilfield for cementing subterranean voids and boreholes. After being permitted to harden in the subterranean void, the hardened foamed cement slurry often has low permeability and high strength relative to other equivalent density cements prepared from slurries other than that of the instant invention. While this is the preferred method of preparing the foamed slurry, other high shear mixing devices may be used for this purpose.

**Example 1**

By way of example, the following embodiments of foamed slurries of the invention are prepared. The cement component is an API Class H cement having a surface area of about 2500 cm<sup>2</sup>/g (by SediGraph 5000). The "extender" in half of the embodiments is a fly ash (LaDue) having a surface area (also by SediGraph) of about 3500 cm<sup>2</sup>/g. Anhydrous sodium metasilicate is present in each slurry at a level of about one percent, based on weight of the cement component ("BWOC"). Foaming agent of Formula (I) is present at about 0.5-3 percent, based on volume of water. Gas is entrained in the foaming agent-containing slurry prepared from the dry components and water. Resultant foamed slurry densities are described in the following Table I.

TABLE I							
	Slurry	Gas	Percent By Volume of Slurry Water	Percent Solids	Percent Extender BWOC	Density of Foamed Slurry in kg/m <sup>3</sup> (lb/gal)	
15	A	56	24.6	19.4	—	852 (7.1)	15
	AA	56	24.6	19.4	50	768 (6.4)	
	B	56	32.5	11.5	—	684 (5.7)	
	BB	56	32.5	11.5	50	636 (5.3)	
20	C	50	28	22	—	972 (8.1)	20
	CC	50	28	22	50	864 (7.2)	
	D	50	37	13	—	780 (6.5)	
	DD	50	37	13	50	720 (6.0)	
	E	40	33.6	26.4	—	1164 (9.7)	
25	EE	40	33.6	26.4	50	1044 (8.7)	25
	F	40	44.4	15.6	—	936 (7.8)	
	FF	40	44.4	15.6	50	864 (7.2)	
	G	30	39.2	30.8	—	1356 (11.3)	
	GG	30	39.2	30.8	50	1224 (10.2)	
30	H	30	51.8	18.2	—	1092 (9.1)	30
	HH	30	51.8	18.2	50	1008 (8.4)	
	I	20	44.8	35.2	—	1560 (13.0)	
	II	20	44.8	35.2	50	1392 (11.6)	
	J	20	59.2	20.8	—	1248 (10.4)	
35	JJ	20	59.2	20.8	50	1152 (9.6)	35

**Example 2**

Utilizing the basic slurry of Example 1AA, various surfactants are substituted as the foaming agent. The base slurry is mixed in a Waring blender at high speed, with a special screw-on lid for the blender, the lid having a small 1.9 cm (3/4 inch) hole in its center. After the solids/water blend is mixed for about 30 seconds to form a homogeneous slurry, about 1-2 percent, based on volume of water, ("BVOW") of a solution of foaming agent is injected through the hole in the lid. The most preferred foaming agents of the invention generate an immediate foam which fills the blender chamber in about 2-5 seconds with a small bubble, uniform foam, having an average bubble diameter of 0.5 mm or less. The foam when permitted to stand for 15-20 minutes remains uniform and stable without appreciable collapse or defoaming. When allowed to cure, the resultant hardened foamed cement often has permeability of about 0.1 millidarcy or less.

When less preferred foaming agents of the invention are substituted, from 5-20 seconds may be required to fill the chamber after introduction of the foaming agent. The resultant foam has relatively uniform, small bubbles of an average diameter of 1 mm or less. There may be a small number of noticeably larger bubbles. The foam is fairly stable without significant collapse in 15-20 minutes. When allowed to harden, the resultant foamed cement often has permeability on the order of from 0.2 to 1 millidarcy and a cross-section of the hardened foamed cement will show only minor gravity segregation of solids and gas bubbles.

When other surfactants outside the limits of Formula I are employed as the foaming agent, the chamber may not fully fill even after 1-2 minutes of shearing, may require significantly more than 3 percent (BVOW) foaming agent to fully fill the chamber with foam, if at all, and may exhibit substantial foam collapse after standing 15-20 minutes. The foam may contain a significant portion of bubbles having average diameter greater than one mm and the hardened resultant cement, if remaining foamed at all, may exhibit severe segregation and stratification of bubbles and solids resulting in highly permeable portions in the upper part and dense, impermeable portions in the lower part.

**Example 3**

A cement slurry is prepared from a 35:65 (weight) pozzolan:Class G cement blend with sufficient water to make about a 1680 kg/m<sup>3</sup> (14 pound per gallon) slurry. About 59.2 m<sup>3</sup> (370 barrels) of the slurry is prepared with the addition of about 1 percent of anhydrous sodium metasilicate, about 18 percent sodium chloride

and about 0.7 percent of a calcium lignosulfonate retarder (all BWOC). To the slurry so prepared is added about 1.5 percent (BVOW) of a foaming agent comprising (by volume) about 3 parts trimethylcocoammonium chloride and about 1 part bis(2-hydroxyethyl) cocoamine oxide, in about an equal volume of iso-propanol. To this 59.2 m<sup>3</sup> (370 barrels) of slurry containing the foaming agent is added about 3500 m<sup>3</sup> (125,000 standard cubic feet) of nitrogen by injecting through a "tee" to the line containing the slurry. The line is thereafter split into 2 lines at the "tee" and the 2 lines are later recombined at another "tee" through a choke device in each of the lines causing the 2 slurry streams to impact with considerably turbulence and good mixing as described earlier. The rate of nitrogen addition to the slurry is varied, in a staged fashion, throughout with more being added to slurry intended for the bottom of the hole and less to slurry added to the top. In this fashion, a slurry of relatively uniform density of about 1260 kg/m<sup>3</sup> (10.5 ppg) from top to bottom of the hole is obtained. The cement slurries are used to cement a five and one-half inch casing to a depth of about 2490 m (8300 feet) in a previously drilled borehole. About 8 m<sup>3</sup> (50 barrels) of a gelled spacer fluid is first pumped into the casing followed by about 4.8 m<sup>3</sup> (30 barrels) of an aqueous surfactant wash solution. Then about 3.84 m<sup>3</sup> (24 barrels) of the 1680 kg/m<sup>3</sup> (14 ppg) base slurry follows after which the remaining 59.2 m<sup>3</sup> (370 barrels) of slurry to which the nitrogen has been added are pumped, followed by about 14.4 m<sup>3</sup> (90 barrels) of a 36:65 pozzolan:Class G tail-in slurry made up to about 1800 kg/m<sup>3</sup> (15 ppg). About 30.4 m<sup>3</sup> (190 barrels) of salt water is then pumped until returns of the spacer fluid and chemical wash are seen. The well bore is then shut in and the cement slurries are permitted to set. In this manner, a "long-string" casing job is completed in one single pumping operation without having to "stage" the different cement slurries over the desired intervals of the borehole.

Instead of varying the gas addition, the gas may be metered into the slurry at about a constant rate. The resulting slurry will be of greater density near the bottom of the wellbore when in place and of lesser density near the top. The density of the foamed slurry being pumped into the wellbore can be monitored by an instrument commonly used in oilfield service called a densiometer.

## CLAIMS

1. A foamed hydraulic cement slurry comprising an aqueous slurry of hydraulic cement, an entrained gas in the form of multiple, discrete bubbles and a foaming agent represented by the formula
 
$$R(R'-)_3 N^+ X^-$$
 wherein X is chloride, bromide, iodide or hydroxyl, R is an aliphatic hydrocarbyl radical having from 8 to 16 carbon atoms and R' is, independently each occurrence, an alkyl radical of one to three carbon atoms or hydroxyethyl, and the sum of the carbon atoms in R and all R' is not greater than 20.
2. A foamed slurry as claimed in Claim 1 wherein R has 10 to 14 carbon atoms.
3. A foamed slurry as claimed in Claim 1 or Claim 2 wherein R is a fatty alkyl radical.
4. A foamed slurry as claimed in any one of the preceding claims wherein R is a straight chain hydrocarbyl radical.
5. A foamed slurry as claimed in any one of the preceding claims wherein R represents a mixture of hydrocarbyl radicals derived from a vegetable oil.
6. A foamed slurry as claimed in Claim 5 wherein the vegetable oil is cocoa oil.
7. A foamed slurry as claimed in any one of the preceding claims wherein each R' independently is methyl, ethyl, or, in up to two occurrences, hydroxyethyl.
8. A foamed slurry as claimed in Claim 7 wherein each R' independently is methyl or hydroxyethyl.
9. A foamed slurry as claimed in any one of the preceding claims wherein the sum of the carbon atoms in R and all R' is at least 12.
10. A foamed slurry as claimed in Claim 8 wherein the sum of said carbon atoms is between 13 and 19.
11. A foamed slurry as claimed in Claim 10 wherein the said sum is between 14 and 18.
12. A foamed slurry as claimed in any one of the preceding claims wherein X is chloride or hydroxyl.
13. A foamed slurry as claimed in Claim 12 wherein X is chloride.
14. A foamed slurry as claimed in any one of the preceding Claims wherein R is a hydrocarbyl radical of an average chain length of from 10 to 14 carbon atoms, R' is, independently each occurrence, methyl, ethyl, or in up to two occurrences hydroxyethyl, and X is chloride.
15. A foamed slurry as claimed in Claim 13 wherein the foaming agent is trimethylcocoammonium chloride, methyl bis(2-hydroxyethyl) cocoammonium chloride, trimethyldodecylammonium chloride or a mixture thereof.
16. A foamed slurry as claimed in any one of the preceding claims wherein the foaming agent is present, by volume, in an amount of from 0.1 part to 3 parts per 100 parts water.
17. A foamed slurry as claimed in Claim 16 wherein the foaming agent is present in an amount of from 0.5 to 1.5 part per 100 parts water.
18. A foamed slurry as claimed in any one of the preceding claims, further comprising bis(2-hydroxyethyl) cocoamine oxide.
19. A foamed slurry as claimed in Claim 18 wherein said oxide is present in an amount of about 1 part, by volume, per 3 parts of the foaming agent, and the foaming agent is trimethylcocoammonium chloride.

20. A foamed slurry as claimed in any one of Claims 1 to 17 further comprising an ethoxylated derivative of a foaming agent as defined in Claim 1 in which at least one or two R' are hydroxyethyl.
21. A foamed slurry as claimed in Claim 20 formed by addition of about 15 moles of ethylene oxide to cocoamine and subsequent reaction with methyl chloride.
- 5 22. A foamed slurry as claimed in any one of the preceding claims wherein the aqueous slurry further comprises, by weight, from 0.5 part to 3 parts sodium silicate per 100 parts of the hydraulic cement component. 5
23. A foamed slurry as claimed in any one of the preceding claims wherein, by volume, the solids therein comprise from 10 to 35 percent of the foamed slurry, under conditions of use.
- 10 24. A foamed slurry as claimed in Claim 23 wherein said solids content is from 15 to 30 percent. 10
25. A foamed slurry as claimed in any one of the preceding claims wherein, by volume, the gas comprises from 20 to 55 percent of the foamed slurry, under conditions of use.
26. A foamed slurry as claimed in Claim 25 wherein said gas content is from 25 to 50 percent.
- 15 27. A foamed slurry as claimed in any one of the preceding claims wherein the average diameter of the said bubbles is less than 1.0 mm. 15
28. A foamed slurry as claimed in Claim 27 wherein said diameter is less than 0.5 mm.
29. A foamed slurry as claimed in Claim 28 wherein said diameter is less than 0.3 mm.
30. A foamed slurry as claimed in any one of the preceding claims wherein the cement is a Portland cement.
- 20 31. A foamed slurry as claimed in any one of the preceding claims which further comprises particles of finely divided fly ash having surface area of about 3000 cm<sup>2</sup>/g or greater and the surface area of the hydraulic cement component is about 2000 cm<sup>2</sup>/g or greater. 20
32. A foamed slurry as claimed in any one of the preceding claims which further comprises finely divided silica.
- 25 33. A foamed slurry as claimed in any one of the preceding claims wherein the foaming agent is present in an amount sufficient to permit the major portion of said gas to remain as discrete bubbles at a temperature of about 65.6°C (150°F) or greater until said slurry has hardened. 25
34. A foamed slurry as claimed in Claim 1 and substantially as described in Example 1.
- 30 35. A process for plugging a subterranean void with a lightweight, relatively impermeable plugging agent comprising emplacing a foamed slurry of any one of the preceding claims in the void and permitting same to harden. 30
36. A process as claimed in Claim 35 wherein the foamed slurry is subjected to a temperature of about 65.6°C (150°F) or greater prior to hardening.